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SERIE RESEARCH MEMORANDA

ENERGY DEMAND IN A LONG-TERM PERSPECTIVE:
POSSIBLE IMPLICATIONS OF TIME SCHEDULING

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**VRIJE UNIVERSITEIT
FACULTEIT DER ECONOMISCHE WETENSCHAPPEN
EN ECONOMETRIE
AMSTERDAM**

**ENERGY DEMAND IN A LONG-TERM PERSPECTIVE:
POSSIBLE IMPLICATIONS OF TIME SCHEDULING**

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1. Cheap Energy: A Doubtful Blessing

The past years have been marked by a drastic decline of interest in energy problems. Being a neglected issue before the seventies, the energy problem has become a hot item on policy agenda's in the seventies, followed by a gradual decrease as a policy priority in the eighties. Energy issues seem to follow the life cycle trajectory of any other commodity in a mature economy. And the policy interest exhibits the usual stages of a policy life cycle model (see also Le Clercq, 1987):

- (1) acknowledgement of the need to formulate a new policy
- (2) policy formulation
- (3) realization of a solution
- (4) maintenance of the solution system developed.

The previous remarks may lead to the following policy interest cycle as a derivative of the urgency of energy problems (i.e., scarcity of oil).

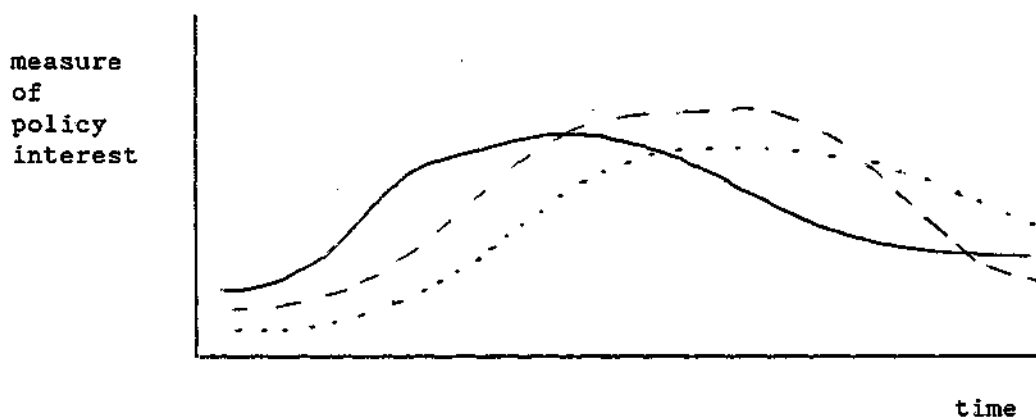


Figure 1. Policy interest cycle and policy response cycle as a function of energy scarcity.

Legend: _____ urgency of energy problems (e.g., oil price)
----- awareness (i.e., degree of policy interest)
..... policy response (i.e., intensity of energy savings programmes).

Although relatively cheap energy may act as a favourable fertilizer for

economic recovery, this new situation has also various negative consequences:

- a future orientation towards alternative and new oil resources may stop;
- energy consumers may return to using 'abundant' cheap oil (with all its negative environmental spillovers);
- public funding of R & D in energy may decline.

A careless attitude regarding energy use and supply, however, tends to induce exactly the above-mentioned cyclical patterns (see also A. Rutgers van der Loeff, 1986), as then our economies become extremely vulnerable in terms of energy provision, especially if unexpected events would occur. Thus, seen from a long-term perspective, an active energy policy is necessary to prevent "surprise events" which might destabilize our economies. The 'shadow costs' of an inappropriate energy policy in the period before the 1970s are still putting a severe burden on our economies nowadays.

Apart from risk-strategic considerations there are also other reasons why strict energy policies still make sense. First, energy R & D - being a relatively young field of technological research - is not only a vehicle for finding a more efficient exploitation of renewable energy resources or a more appropriate conversion and use of primary energy sources, but it may also generate various new spinoffs at a national or regional basis in terms of highly competitive high-tech developments (e.g., active and passive solar heating for buildings, photovoltaic electricity production, transformation of biomass into useful energy, use of wind generators for electricity production, geothermal energy production, etc.). Thus for specific regions energy technology might act as an incubator or seedbed for improving the region's competitive position (cf. Johansson and Lakshmanan, 1985).

In the second place, energy policy is not independent of any other technical option. In particular, physical planning and environmental planning are closely related to energy savings policy; pollution certainly does not decrease with a decreasing oil price (Strub, 1987).

Given the lead time of up to 30 years, there is a definite need for a joint future-oriented active 'policy package' in this field. A brief example may clarify this point. Less than two decades ago, the conflict between fuel efficiency and pollution abatement strategies in the automobile industry was thought to constitute an inexorable technical trade-off, but one decade later already new adjusted technologies (e.g., the three-way catalyst and microprocessor combustion controls) were able to double the average fuel efficiency of most American cars (cf. Roos and Altshuler, 1984).

Finally, energy costs determine to some extent the competitive position of various regions, especially those which are marked by high transportation costs or the presence of large energy consumers (aluminium industry, e.g.). In this respect, it may be extremely important to obtain a reliable assessment of the future utilization of energy networks. Like other types of physical infrastructure, energy networks are very capital intensive, and this may imply that in case of underutilization capital costs are excessively high. On the other hand, overutilization usually increases the probability of system-wide disruptions, which incurs also high costs. Moreover if disruptions are frequent, the periodical overutilization may result in an annual underutilization.

The long-run optimization of the network size can be viewed of as a three phase cyclical planning effort:

1. forecasting the long-run development of the utilization patterns based on expected changes in the economic, social and technical characteristics of the network users;
2. assessing the physical network requirements given the forecast of these utilization patterns;
3. assessing the feasibility and effectiveness of load management in order to save on peakload capacity and increase the expected utilization rate. If load management seems feasible and effective, then, of course, the future physical network requirements have to be adapted.

So initially the strategy is passive, i.e. what utilization schedule emerges? Subsequently, this schedule may be altered due to load management policies. Notice that in this case we talk about proposed load management policies in order to reschedule expected utilization patterns. It is clear that load management can also be used in the short run, to optimize the use of the existing network. As regards this last subject (load management with respect to the existing network in order to evade investments in new capacity) already quite some research has been accomplished, notably in the USA and also in France, both practical and more fundamental research (see. inter alia, Mitchell (1980), Caves (1980), Caves et al. (1987) and Train et al. (1987)).

The present paper will discuss an assessment approach with respect to the first phase (future utilization patterns). The instrument to be discussed has been developed during a study contributing to the MEDEE-EUR model of the Commission of the European Communities. Therefore we will indicate first the historical background of the approach and its relation with MEDEE-EUR in section 2. Next, section 3 will provide a general introduction about scheduling activities in society, with special reference to electricity networks. A concise description of the model will be presented in section 4. Section 5 contains some preliminary results.

2. Energy Systems Analysis in the Common Market and the Concept of MEDEE

The Commission of the European Communities has launched a research programme on energy systems analysis with the broad aim to develop quantitative analytical instruments for energy and energy-related systems (e.g., economy, environment, industry). In this context, a wide variety of models and information systems for energy analysis has been developed, inter alia some models for the medium- and long-term simulation and forecasting of energy. Examples of such models are EFOM, STEM, MIDAS, HERMES, and MEDEE. A brief overview of some existing models will be given in Annex A. As the MEDEE model will also be used

in our paper, a slightly more detailed discussion of its structure and its functioning will be given here.

The MEDEE model is able to generate (by means of simulation experiments or scenarios) consistent future pictures of the energy demand at a detailed (socio-economic, spatial and technological) level. It aims at forecasting the energy use of various end-use categories in the long run (thus allowing the possibility of technological adjustments). The model itself has a modular, hierarchical structure incorporating various modules for categories of energy consumers (industry, households, etc.). These modules are linked together in a coherent way, while intra-modular relationships are included in a very detailed way. The behavioural content of the MEDEE model is not strongly developed; the model serves mainly as an engineering model. The model is able to incorporate both quantitative data and qualitative information, thus assuring a high degree of flexibility (more details and an application to the Netherlands can be found in Nijkamp and Tiemersma, 1985).

As mentioned before, the MEDEE model has a detailed modular structure for various end-use categories, geographical units and technological options. The following scheme (Figure 2) pictures the global structure of the MEDEE approach. The two blocks at the left-hand side of Figure 2 deal with international developments and national economic developments. Various assumptions on the patterns of growth in these two systems lead to various scenarios which can be introduced as inputs into the MEDEE model.

The approach adopted by us is closely related to the MEDEE principles. This applies in particular to the engineering approach. Our contribution to the MEDEE study also aimed at the development of a user-friendly concept that could be used on a PC. Therefore no actual integration with the MEDEE model has taken place. However, the structure, the nomenclature and the distinction in sectors are similar to the industrial module of the MEDEE-EUR model. The present version of the model is limited to electricity networks (and to some extent natural gas).

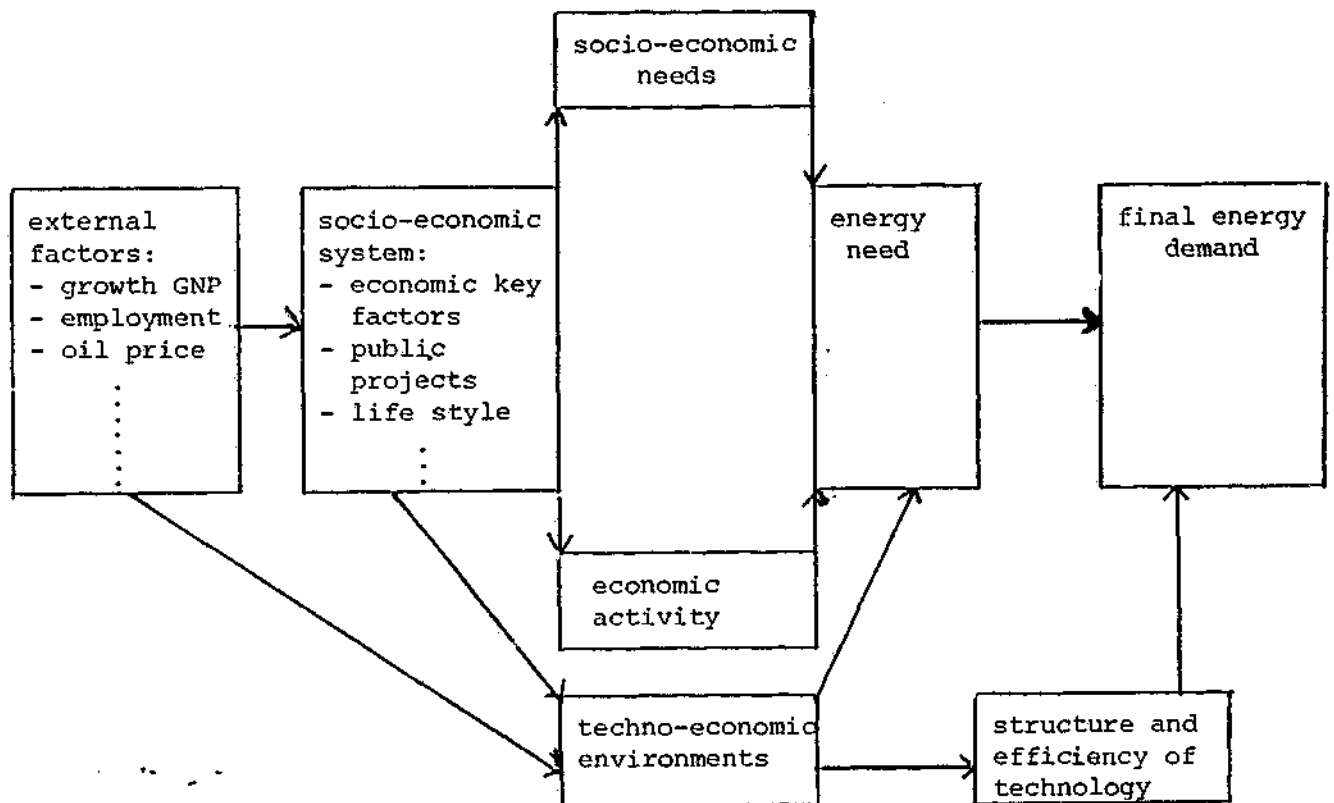


Figure 2. Simple structure of the MEDEE approach.

3. Time Scheduling and Energy Efficiency

The preponderant motive behind our approach is that most probably in the future energy consumption and delivery will mainly take place via energy supply networks. Such networks have a limited capacity and in general no possibility for storing energy. Hence the utilization pattern of energy (in terms of hourly, daily and seasonal fluctuations) is a crucial cost factor here. Peak consumption, caused by specific time activity patterns of energy users, may lead to a necessary capacity of energy networks which is far above the average energy use. Therefore, it is of great interest to analyze the scheduling pattern of economic activities through time, as here a substantial rise in efficiency may be gained. This can be illustrated by means of a so-called load curve. An example of such a load curve is presented in Figure 3. This load curve depicts the amount of generation power which is in use on a certain moment of the day. If one knows the total amount

of generation power (here depicted by the straight line at the top of the figure) one gets an impression of the rate of utilization of generation power. It will be clear that if a part of the daytime activities would be shifted to the night the load curve would level off and consequently the necessary amount of generation power would decrease.

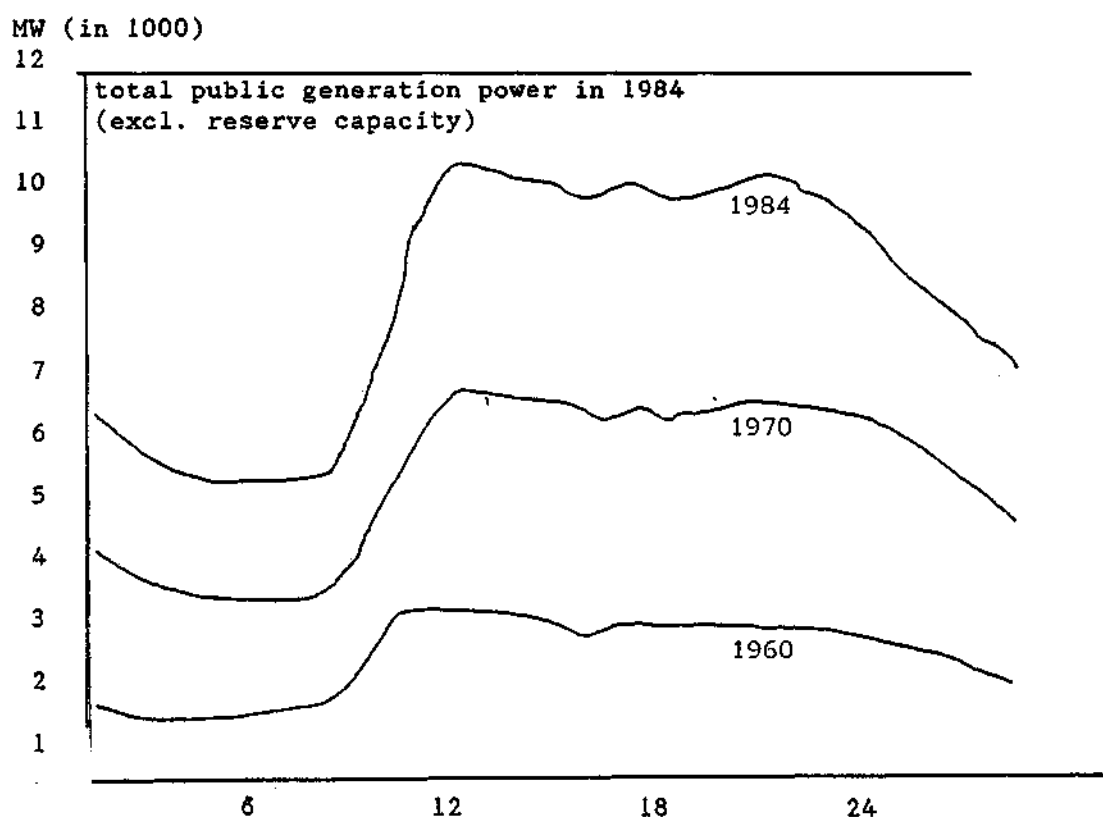


Figure 3. Highest electricity day load curves in the Netherlands in 1960, 1970 and 1984.

Source: Electriciteit in Nederland 1984 (SEP/VEEN, Arnhem, 1985).

The possibilities for time scheduling have to be seen against the background of structural shifts towards non-basic industries, so that time scheduling in these industries is likely to have substantial impacts on the required amount of day load capacity of electricity generation power. These structural changes are induced inter alia by informatics, telematics and robotics which allow in principle a more flexible and longer daily activity pattern. Efficient scheduling of

time (budgets) is thus probably a major challenge in energy policy analysis, as this may significantly increase the efficiency of existing energy networks.

Until the mid 1970s economic growth was regarded almost synonymous to increasing quantities of physical output. Since the energy crisis, however, the qualitative aspects of economic growth have become increasingly important. Qualitative growth implies here a rise in value added with only a slight increase in physical output. This notion applies also to energy consumption. The electricity of energy in relation to output used to be approximately equal to 1 (or sometimes higher). However, in recent years this elasticity is approximately 0.6. This means that a significant reduction in energy elasticity has been achieved as a combined result of effective energy savings investments and a shift from quantitative to qualitative growth.

In this context, the utilization schedule of energy networks is of great importance. Competitive end-use prices require a careful utilization policy, in which high investments caused by peak consumption have to be avoided. Especially in case of electricity power plants, the average overcapacity causes enormous costs. Until the mid 1970s the major aim of investments in electricity networks was to meet future demand. But alternative goals have increasingly come to the fore, notably the aims of environmental management (witness the various large-scale NO_x and SO_2 abatement programmes in various countries) and of competitive prices in order to overcome the economic stagnation. As electricity cannot be kept in stock, the demand pattern of energy through time determines to a large extent the composition of the generation capacity. Of course the ultimate problem is whether the difference between baseload and peakload can be reduced by means of a re-scheduling of economic activities. However the establishment of a consistent and lasting load management policy requires insight in the structural causes and processes determining the load pattern. Presently we confine ourselves to this last issue, the assessment of the load pattern.

The analysis of time scheduling is certainly not a well developed field

(see among others Becker, 1965; Gronau, 1977; Winston, 1982; Kooreman and Kapteyn, 1984). Unfortunately, data on time scheduling behaviour are extremely scarce and its analysis is difficult, as we are dealing here with 2 simultaneous actions, viz. capital utilization by firms and time budget allocation by individuals. The picture we have so far is somewhat diffuse, as various structural developments are taking place at the same time, like automation, increasing labor force participation, increase of leisure time, flexible working hours, and telecommuting (see also Figure 3). In the next section, the design of a first model for forecasting the utilization of energy networks by means of time scheduling data - named TISED (Time Schedule dependent Energy Demand model - will be presented. It is derived from the MEDEE model and can be run on a PC.

4. A Model for Time Scheduling in Energy Systems

4.1 Assessing Momentary Utilization

Time activity patterns of individuals, groups and firms in an economy are usually organized in accordance with their priorities, given various limits on these activity patterns. The use of various goods (e.g., heating, transport, energy) is codetermined by such activity patterns. Clearly, such time patterns exhibit various regular time fluctuations (daily, weekly, annually), caused by biological, social and economic circumstances. However, it is clear that the time preference of individuals is not uniformly distributed for 24 hours of a day. In general, night work has a higher price, and therefore a firm is facing a trade-off between a higher utilization rate of capital (and hence a higher wage rate) or a lower utilization of capital (and hence a lower wage rate). Therefore, shift work has only taken place in highly capital-intensive industries like steelworks, aluminum, and paper mills. The main framework of activities in our economy is hence still determined by the organization of labor time. This has also important implications for the daily time pattern of energy consumption (see also Figure 3).

The purpose of the present model is to analyze the impact of time scheduling in industry on electricity demand, not only on an annual basis, but in particular for each period of the day. The momentary electricity demand is difficult to assess, as data are extremely scarce. However, momentary electricity demand is a capital-related concept and hence we may use proxies for the momentary use of capital. At this point we have to make a choice between a micro-oriented approach or a macro-oriented approach. A micro-oriented approach implies the extensive use of numerous actual measurement tests of momentary electricity in relation to capital utilization consumption. A macro-approach requires the availability in current statistics of an indicator for momentary capital utilization. The micro-oriented approach will certainly produce more precise indicators at the micro level, but there is no guarantee that this preciseness can be maintained at the macro level. Moreover this micro approach is extremely time consuming and consequently quite expensive ¹ in particular if it has to be used in a cyclical planning process. As a consequence we turned to the macro approach despite its limited (initial) reliability. It is recommended to use (additional) micro-based data to support (and improve) the indicators at the macro level.

A major problem is the assessment of the capital stock in the sense that we only have to estimate the share of the capital stock that is in operation at a given moment, by assuming that the capital stock is homogeneous in terms of sectoral energy consumption. The shares of shift work categories in the (sectoral) labor force may be a suitable proxy for the shares of the capital stock utilized, assuming that the amounts of labor in each of the shift work categories have identical relations with the amounts of energy consumed per category of capital stock utilized (i.e., identical electricity-labor ratios within a sector). Empirical evidence suggests that this is in general an acceptable initial assumption for labor allocated in 2-, 3- or 4-shift

¹ As soon as automatic measurement of the momentary electricity consumption in the industry would enjoy a more widespread application, the micro approach becomes much more attractive.

operations (see, inter alia, Van Wees (1981), Gerritse en Melman (1985), Ferrels (1984)). That means that by using an appropriate sectoral distinction the greater part of the variation of the energy-labor ratio will be ruled out. However, for 1-shift operations this assumption is a priori likely to be invalid (this is usually daytime labor), the reason being that daytime labor comprises all (production-and non-production-related) employment; in this case the higher share of non-production-related employment leads to a considerably lower energy-labor ratio, so that here the assumption of identical relations between labor and energy for each shift work category is violated. Thus in this case a correction is necessary, at least for the production-related part of energy demand.

The above-mentioned TISED module has the following structure. First, final energy demand is split up into an output dependent and an output independent part (i.e., variable vs. fixed electricity costs). Then the various parts of sectoral electricity demand are distributed among capacity shares, which are directly linked to the sectoral shares of the respective shift work categories. These capacity proxies are obtained by correcting output for shares of shift work classes. At this stage the model calculates a gross load. Next, the network load (i.e., the net load) is calculated by subtracting the industrial cogeneration capacity from the gross load. This requires in fact that also industrial cogeneration capacity is distributed among the sectoral shift work categories. The main structure of the TISED model is pictured in Figure 4.

A few remarks may serve to clarify Figure 4. It is clear that the greater part of electricity use is directly related to output, but a smaller (though not negligible) part is still not (directly) related to production activities, but to general overhead activities of the industry. The production level and the prevailing technology in a firm or sector determine the utilization rate and pattern of the capital stock. The specific part of the capital stock that is in use at a specific moment determines the production-related electricity demand. For instance, during the daytime on working days the entire production

capacity will normally be in operation, while only a small part will be utilized during the night or in the weekends. The remaining part of the momentary electricity consumption relates partly to general facilities (like air conditioning and lighting) and partly to facilities in non-production divisions (like administration). The size of non-production-oriented divisions is assumed to follow the long-run annual output trajectory. A part of this non-production-related electricity consumption has a constant character (e.g., lighting).

We conclude that for each part of the momentary energy demand a capital-related indicator is used, but the way this capital stock is assessed depends on the homogeneity of the relevant energy-labor ratio per shift work category. So the model distributes essentially the annual sectoral energy consumption according to the shares of the corresponding sectoral shift work classes. As the energy demand per shift work category is closely related to a typical period of the day, annual energy demand per sectoral shift work category can be transformed into a part of the daily load curve. Finally, long-term forecasts can be made by introducing growth rates of value added, of specific energy consumption patterns etc. A more detailed description of the model is found in Annex C.

The present version of the TISED model is a preliminary one. Clearly several improvements and elaborations can be implemented. As regards the improvements we plan to introduce seasonal fluctuations, a refinement of the energy-labor ratios and a better assessment of the distribution between production-dependent and production-independent energy consumption. All these improvements depend on the availability of micro level-based data. Several micro level studies have been implemented recently in the Netherlands. The foreseen elaboration of the model aims at covering the total load of the public network. To attain such a complete coverage several modules have to be developed. An impression of the fully fledged system is provided in Figure 5.

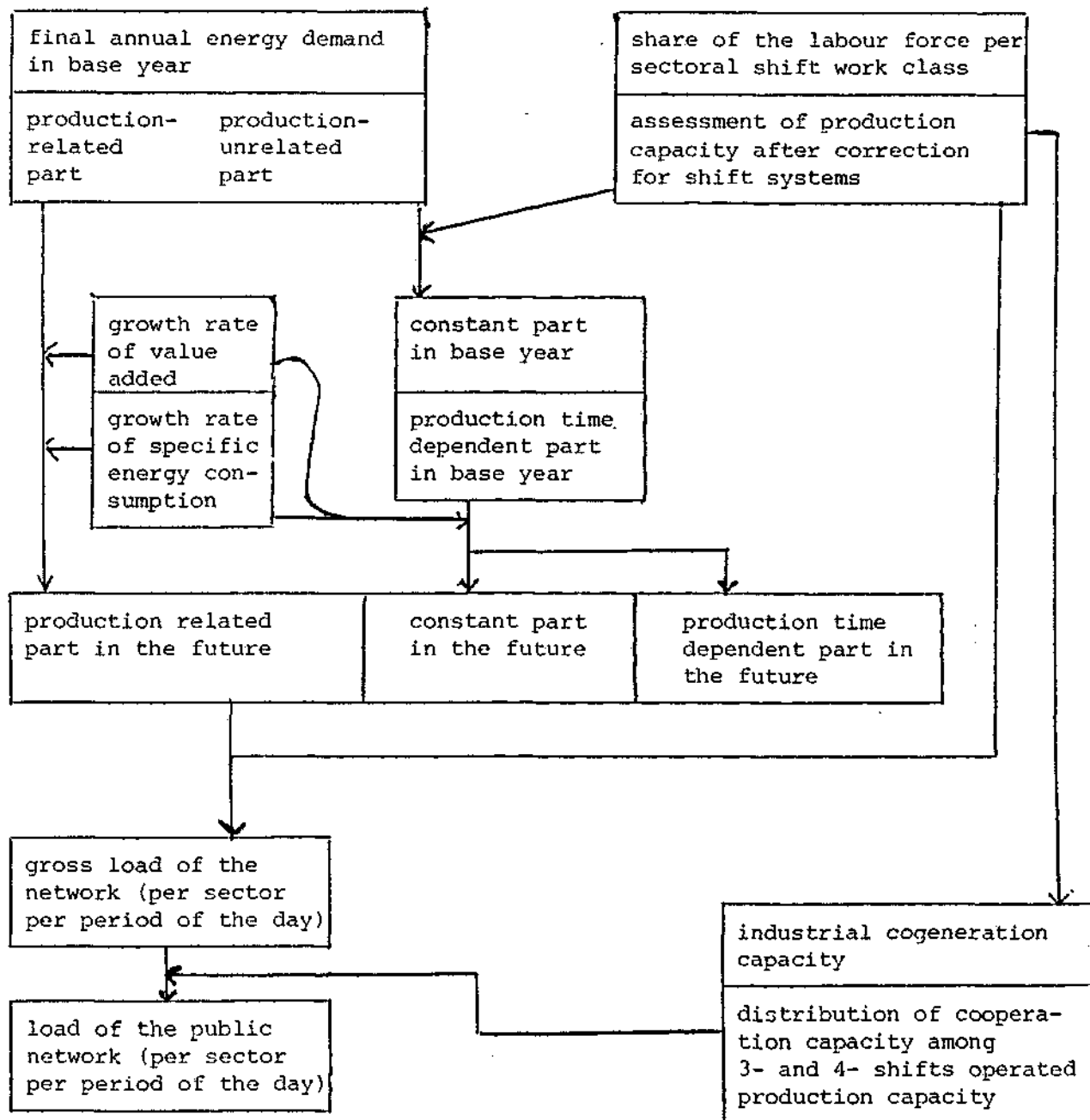


Figure 4. The principal relations in the TISED model.

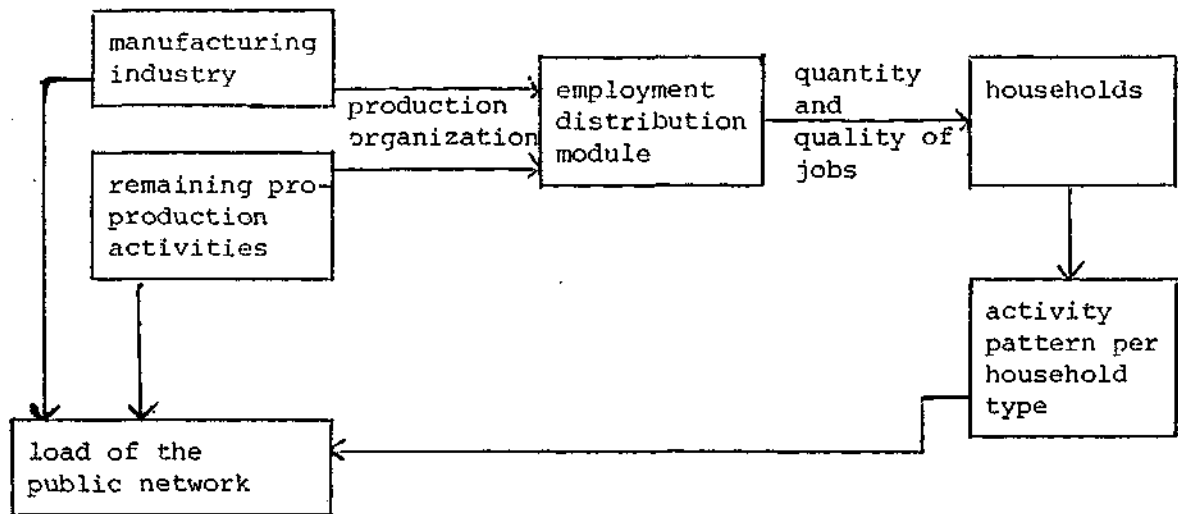


Figure 5. Foreseen extension of the TISED model.

The model itself can easily be run by means of user-friendly computer software on a PC. The programme contains a menu-operated spreadsheet with the possibility of a graphical display of the results. In this way, the TISED model can also be used in an interactive planning context. Some numerical results will be presented in the next section.

5. Numerical Results

5.1 Validation

The model calculates the annual final electricity consumption as well as the momentary (final) electricity consumption. The discussion in this section will concentrate on results regarding the momentary consumption of electricity.

At maximum four different periods of the day are distinguished by the model. The model simulates a 24 hour period from sunday night until monday night (see Figure 6). During the weekend the load of the network is assumed to be the lowest as only 4-shift operated capacity in the manufacturing industry is assumed to be in operation (SN). During nights of working days 3- and 4-shift operated capacity will be in use

(MN), while the network load on evenings of working days is caused by 2-, 3-, and 4-shift operated capacity (M2). Finally by adding normal daytime operated capacity the load during the daytime (8.00 a.m.-5.00 p.m.) is simulated (M1).

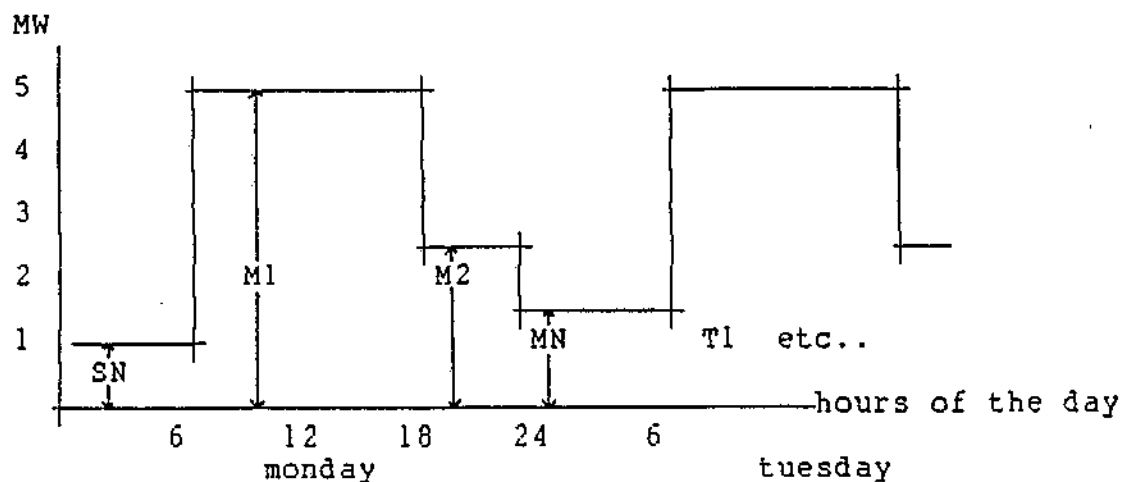


Figure 6. The moments of the day simulated by the TISED-model.

The pictures 11-14, illustrating the impacts of (re-) scheduling, in fact show slices of the (simulated) load curve (per sector) of the different periods of the day as is indicated in Figure 6.

Before discussing some simulated possible impacts of rescheduling we want to try to provide an indication for the reliability of the model. Unfortunately to date a straightforward comparison is impossible as data about the load of the network by industrial sectors are not available. The only - to some extent - comparable data about the load of the network by the industry can be also regarded as first results from not yet completed research. The two sources are the SEP (1987) and Blok et al. (1986).

The data of the SEP refer to a winter day in 1984, while data of Blok

et al. refer to a monday in January 1980 ¹. The TISED simulation data refer to an annual average monday in 1983. So the TISED simulation data lack seasonal variations. However, apart from extra lighting the influence of the winter (or other seasons) on industrial electricity demand is almost exclusively relevant in several subsectors of the food processing industry. Therefore this may only cause more serious differences in the simulated load of the food processing industry.

	SEP (1984,workday in January)				Blok et al. (1980,workday in January)				TISED (1983,annual average)		
	N	1	2	max	avg	N	1	2	SN	M1	M2
SBi 20-38											
excl. 28											
- industry	2500	3200	2700			2600	4900	3500	910	5200	1770
SBi 29-30											
- chemistry	850	600/	850			1450	1450	1450	340	870	490
SBi 33-37		700									
- metal						850	1500	1100	560	1780	810
- other industry (vt,ptm,ov)						700	1750	950	10	2550	470
- aluminum				509	482						
- basic chem.				889	726				330	420	380
- basic metal	800	800	800						560	780	730

legend

N - workdaynight ±02.00h 1 - workday morning ±9.30h
 2 - workday evening ±19.00
 SN - sunday night ±02.00h M1 - monday morning ±9.30h
 M2 - monday evening ±19.00h max - maximum avg - average

Figure 7 A comparison of three (preliminary) assessments of the load of the public network in the Netherlands.

A second source of disturbance is the variation in industrial output between 1980 and 1984. Industrial output, notably of the basic sectors was considerably lower in 1983 then in 1980 and 1984. Clearly this

¹.The simulations of Blok et.al. comprise an entire week.

variation automatically causes the TISED simulations of the baseloads to be systematically lower compared to the other simulations. Allowing for these differences we may conclude that the TISED model underestimates the base load (sunday night, SN). However on the other hand it is quite certain that the other simulations overestimate the baseload. As a consequence of underestimating the baseload (SN) the dayload (M1) is somewhat overestimated by the TISED model. By and large we may conclude that appr. 400 MW should be swapped from dayload (M1) to baseload (SN).¹ The other loads may have to be raised slightly. The largest differences can be located in the sectors chemical industry and food processing. The treatment of the chemical sector seems to need improvement as regards the SEP and Blok simulations. The TISED model should improve the treatment of the food processing sector. This latter conclusion is in accordance with the remarks about improvements with respect to seasonal variations at the end of chapter 4.

5.2 Results of some exercises with the model

Figure 8 displays the simulated network load of the Dutch manufacturing industry in 1983. The aggregate network load as well as the constituent sectoral parts of the load are shown. The basic sector with entirely shift operated capacity like fertilizer and basic metal show little variation between the periods of the day. The basic chemicals sector a well-known large electricity consumer appears to contribute fairly moderately to the load of the public network, due to the substantial amount of cogeneration power in this sector. The most interesting information is however the large contribution to the dayload (M1) from the sectors food processing and metal processing.² This means that far as manufacturing industry is concerned the required amount of

¹ This can be checked by recalculating the annual demand per sector, for instance the load of the chemical industry simulated by Blok et al. is appr. 25 % too high.

² Metal processing comprises:
- metal constructions, foundries, etc.
- machinery
- electrotechnics
- transport equipment.

public generation power suited for dayload service is largely determined by these non-basic industries. As the gravity of economic growth is shifting from basic to non-basic manufacturing activities the growth of electricity demand may be expected to concentrate in the dayload. This may have far reaching consequences for the future composition of public generation power.

The impact of a shift of growth rates from basic to non-basic industries is illustrated in Figure 9. There is a clear disproportionate growth of the dayload compared to the network load during other periods of the day. However, a shift from basic to non-basic industries is not the only development expected to be relevant for the next 15 years. Automation will reshape production organization in the manufacturing industry. Such an automation potential can be

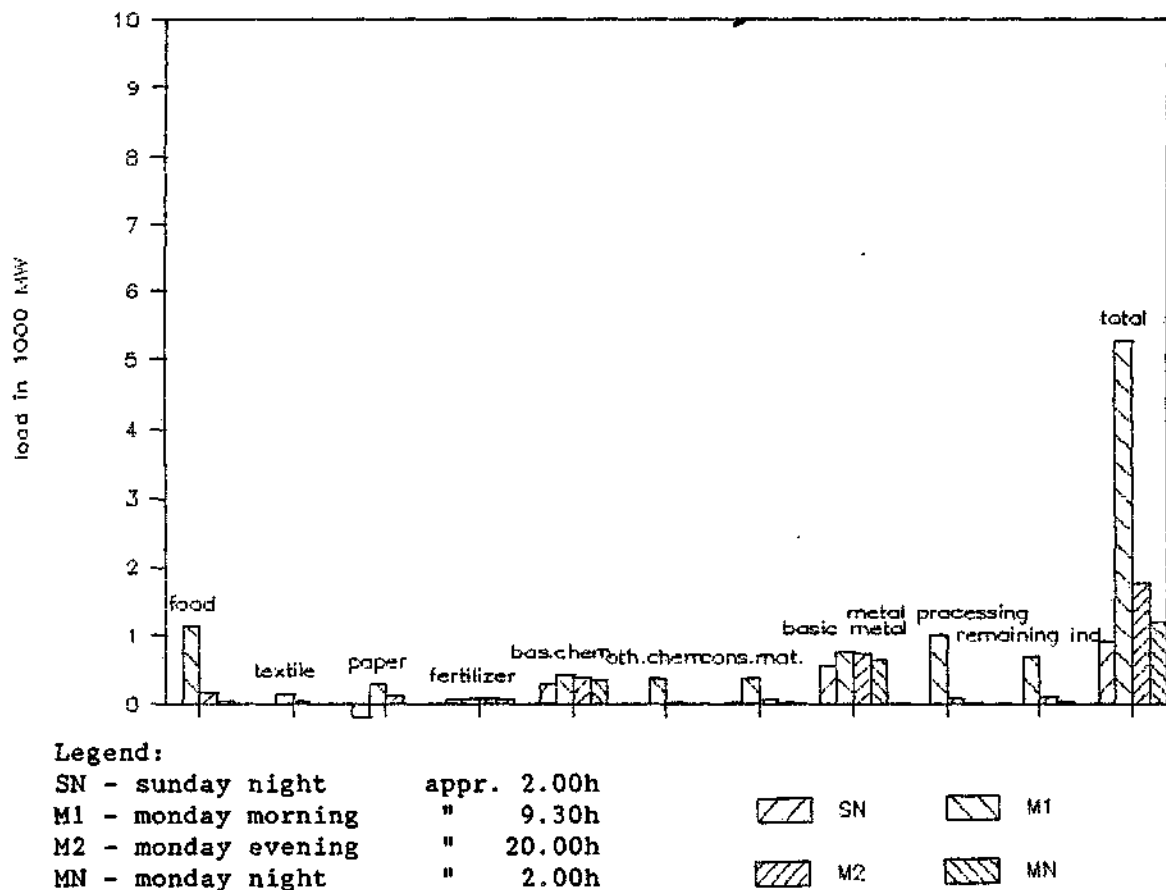


Figure 8 The load of the public network caused by the manufacturing industry in 1983.

found in particular in the non-basic industries. Usually automation will incur a substantial rise of the capital intensity of production in the non-basic industries. However, in order to maintain sufficient rentability of capital it is likely that the utilization rate of capital should be raised. This means that production time has to be increased.

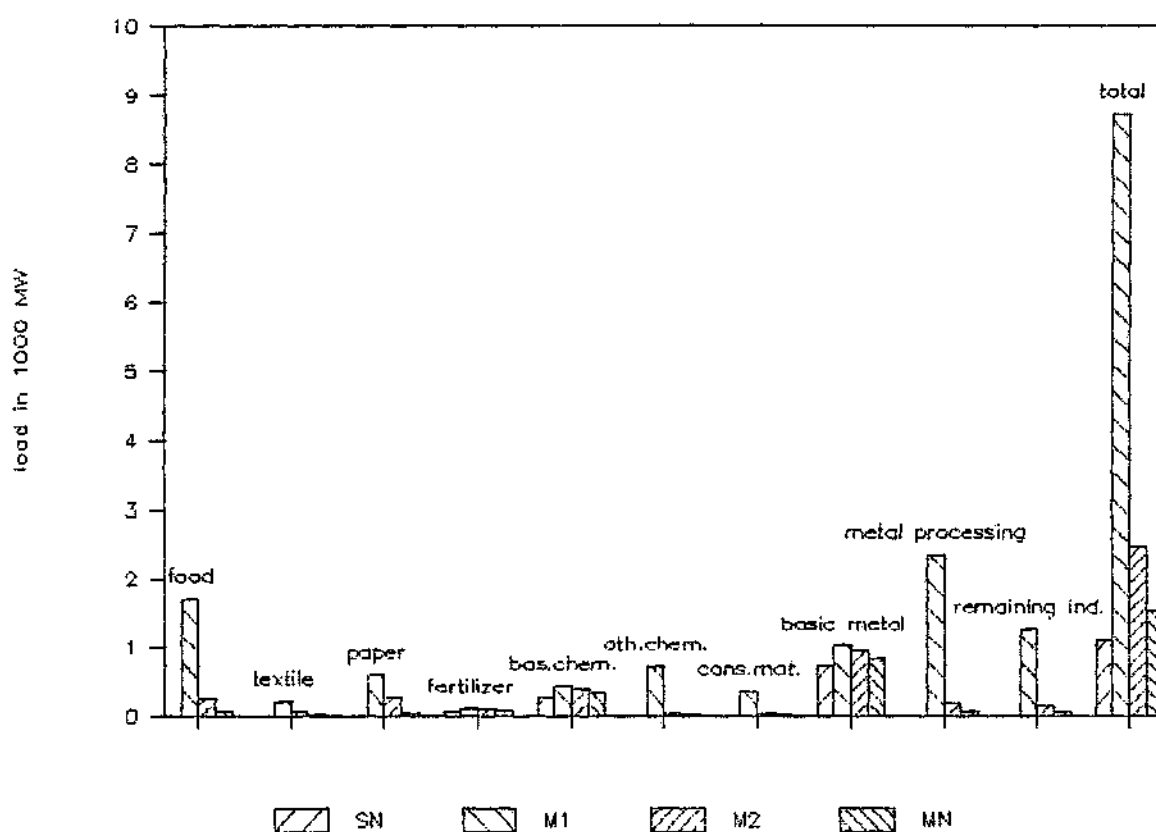


Figure 9. The load of the public network caused by the manufacturing industry in 2000, reference situation.

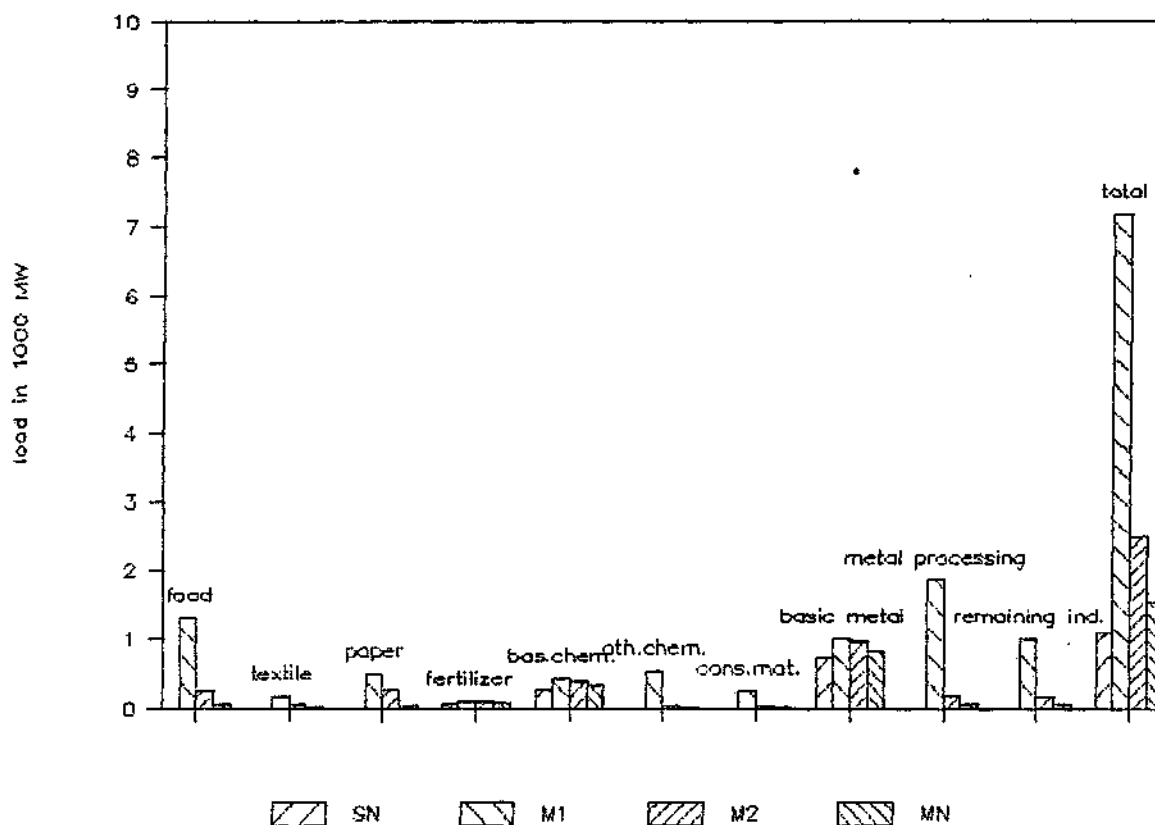


Figure 10. The load of the public network caused by the industry in 2000, extended business hours.

Figure 10 depicts the impact on the load curve in case the traditional daytime production hours are extended from 9 to 11 hours as well as an extension of number of production days per week from 5 to 6. To make such extensions of production time possible more flexible working schemes should be introduced. It is clear that the extension of business hours causes a substantial fall in the required dayload capacity (1200 MW less).

Another possibility for stretching production time is the introduction of shift work. However, this option may be expected to cause larger increases of the labor costs compared to flexible daytime working schemes. Also the option of increasing shift work has been simulated. It should be stressed that within the framework of TISED, next to a real increase of shift work, increasing the shares of shift work can be

used to account for differential developments of energy-labor ratio per shift work class per sector.

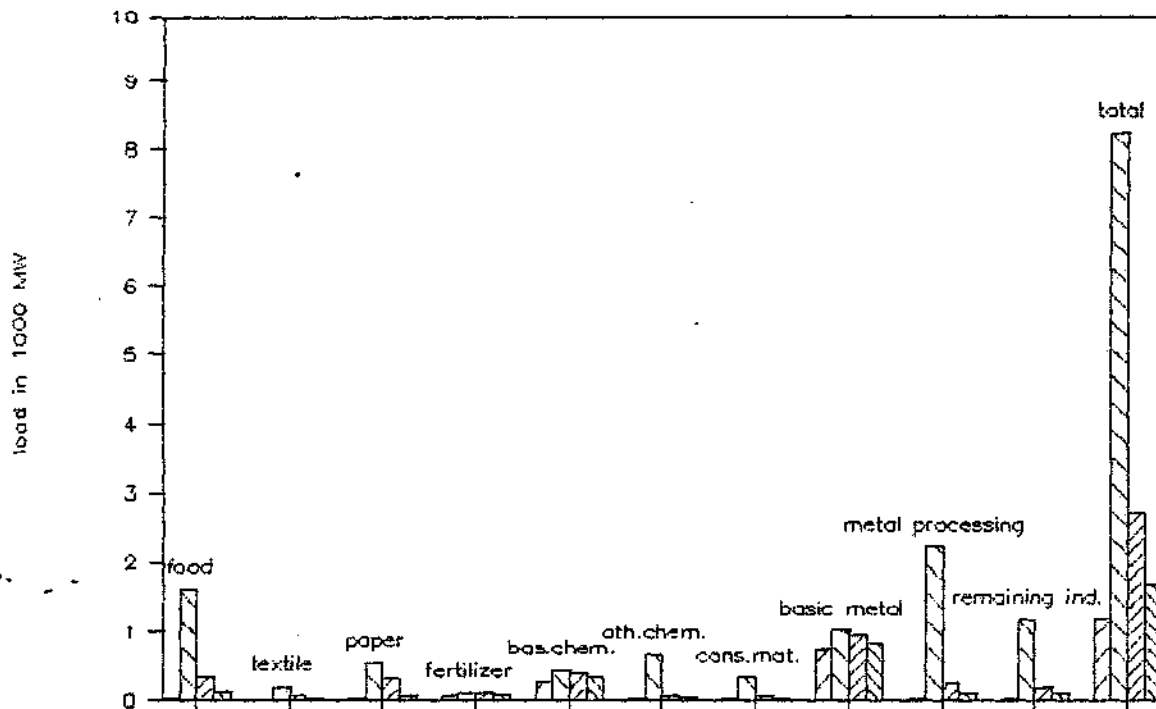


Figure 11. The load of the public network caused by the manufacturing industry in 2000, more shift work capacity.

Figure 11 shows the results of a redistribution of 3 % daytime capacity among multiple shift capacity (2-, 3-, 4-shift classes each 1 %). The impacts are comparable to those depicted in Figure 10, but are smaller due to a smaller shift of the input variables.

6. Concluding Remarks

Energy systems analysis aims at a systematic collection, evaluation and use of energy information at national, regional or local levels with the intention of implementing energy plans or programmes of action or influencing energy policy (cf. Johnson et al., 1986). Efficient energy planning needs the integration of all relevant available energy resources and the promotion of efficient energy use. In addition to

technical solutions, time scheduling of economic activities may offer a great potential for an efficient use of energy electricity networks. The TISED module as part of the MEDEE model appears to be a promising tool.

Clearly, the present version of the TISED module deserves further elaboration, but the first results show that this type of new qualitatively-oriented energy research may provide new insights into the efficiency to be gained by means of flexible time patterns of activities. The household side should also be elaborated in the future, as also here significant efficiency gains are to be expected, not only in terms of energy consumption, but also in terms of utilization of other networks, such as infrastructure.

Annex A. Brief Overview of Energy Models in the Common Market

In this section, 5 energy models will be discussed in a concise way, viz. EFOM, STEM, MIDAS, HERMES and MEDEE.

1. EFOM

This is a medium- to long-term energy supply model; it serves to analyze the main energy supply options. It includes a detailed techno-economic representation of production sector processes (inter alia gas, oil, coal, nuclear power, renewables and electricity). It provides disaggregate balance sheets of both primary and secondary energy levels for various sectors. Extensions with environmental impacts of energy conversion and use are also foreseen (particularly, SO₂ and NO_x emissions).

2. STEM

This is a short-term energy model describing the quarterly trend in total demand and some sectoral demands for the main forms of energy and indicates short-term market trends for the whole of Europe. Demand and supply of energy are confronted at a macro-economic level.

3. MIDAS

This model has a medium-term focus and integrates energy demand and supply systems at a sectoral level. All energy-generating and conversion sectors (gas, oil, coal, electricity) are represented in it, together with the user sectors industry, transport, domestic and services. Energy demand formation mechanisms are estimated by means of econometric methods, while techno-economic modelling is used to represent the supply system. Supply is matched to demand through the price mechanism.

4. HERMES

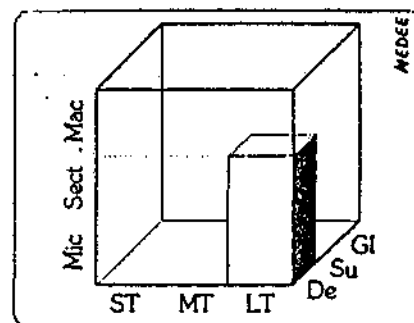
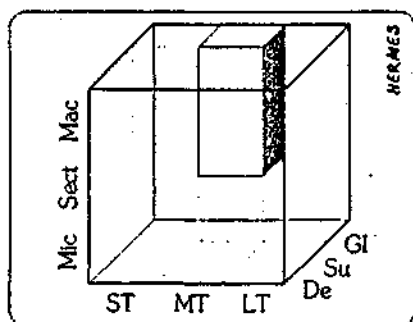
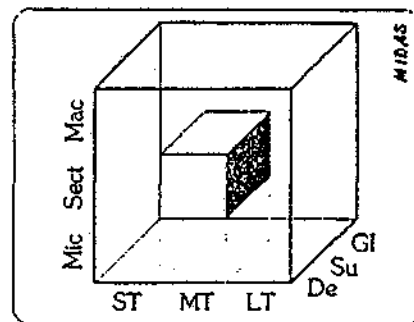
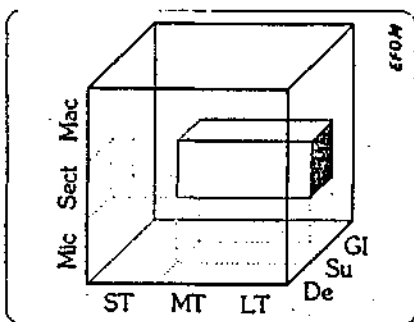
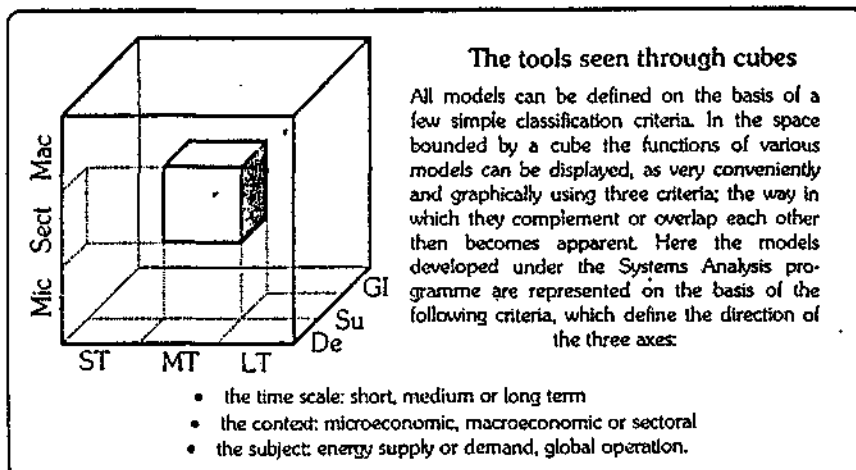
This is a macro-sectoral energy model focusing especially on the demand side in order to provide a more appropriate analysis of the energy-economy interface. Energy is involved at all levels in this model: as a productive branch in its own right; as a production factor associated

with other factors such as investment, employment and intermediate consumption; as a consumer product for households and as a commodity traded between different geographical units. The model embodies a complete formalized economic framework.

MEDEE

This is a long-term energy demand model of a more technical nature. It may cover both micro, sectoral and macro energy developments. It describes analytically the formation of energy demand in the industry, transport, domestic and service sector so as to simulate changes in demand over a long period. It is able to reflect various savings policies and their impacts at a detailed economic, industrial, transport and urban scale. This model originally developed in France is increasingly being used in other countries because of its flexibility, especially since user-friendly computer software became available. This model has also been applied in the context of IIASA's long-term energy study (see Haefele, 1982). More details on this model can be found among others in Chateau and Lapillonne (1979) and Camos et al. (1986).

Figures to Annex A.



Source: ENTECH, vol. 2, February, 1987.

Annex B. A Pictural Outline of the MEDEE model

The socio-economic system is broken down into various modules and sub-modules. The main modules are:

- urban system (different urban heating systems, urban transport modes and tertiary sectors);
- settlement system (geographical patterns of residence, electricity needs, etc.);
- productive system (different industrial sectors and branches, agricultural sectors, etc.);
- transport system (different modes of transport, different trip behaviour, etc.).

The overall structure of the socio-economic system is pictured in Figure B.1, followed by a presentation of the various modules in Figures B2-4. Each of these main modules is extended with detailed submodules, thus making the MEDEE model a large-scale complicated system. However, each of the (sub-)modules can easily be suppressed in the simulation experiments, so that its use is fairly flexible.

The conceptual attachment of the TISED model is illustrated in Figure B3. The MEDEE model can be linked with various long-term socio-economic scenarios, like global scenarios (development of international labor division, e.g.), domestic scenarios (changes in socio-economic or technological policy, e.g.), and modular scenarios (evolution of sectoral innovation, e.g.). See, for instance, the Energy 2000 Study (Guilmot et al., 1986).

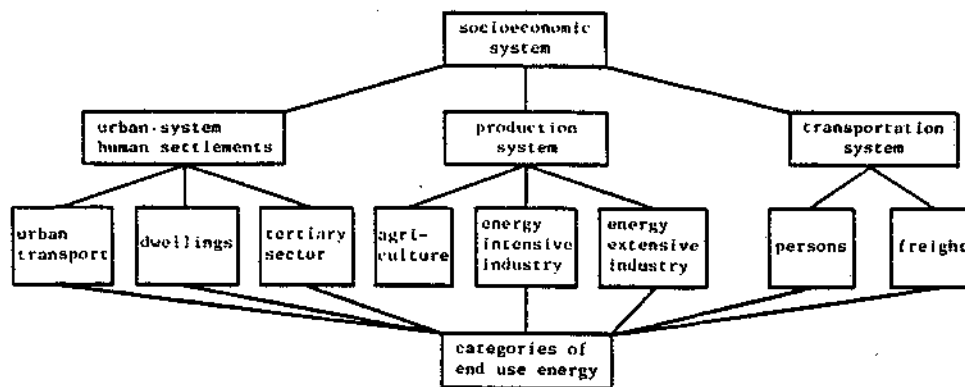


Figure B1. The main structure of the MEDEE model.

- 6 -

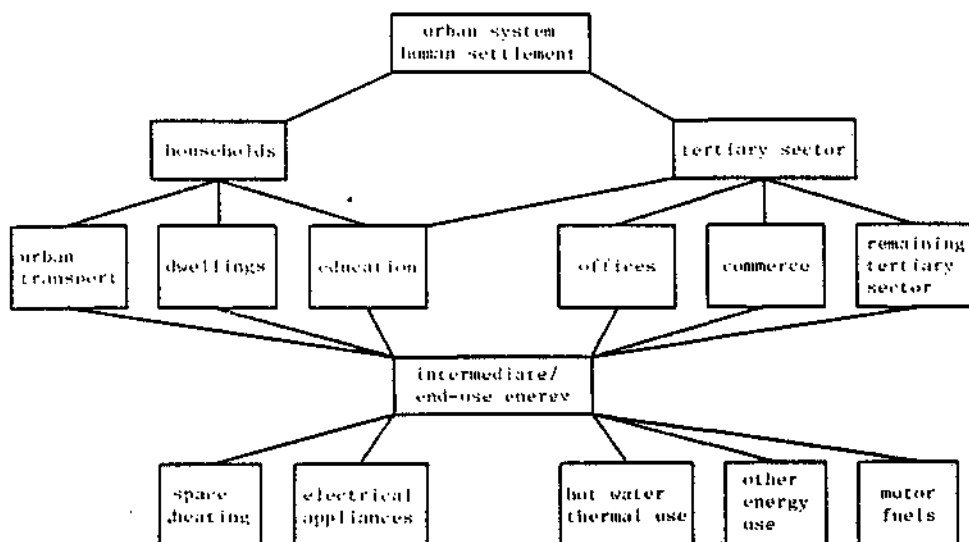


Figure B2. The urban system/human settlement module.

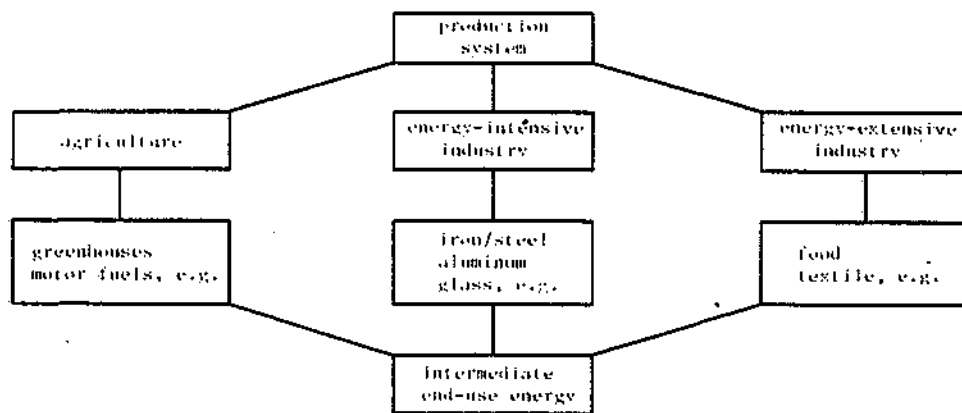


Figure B3. The production system module.

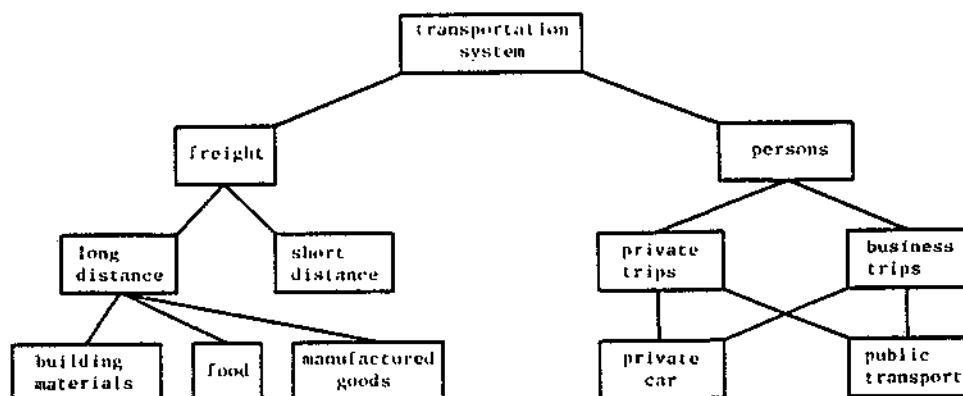


Figure B4. The transportation system module.

Annex C. A Brief Description of the TISED Model

This section will provide the formal description of the TISED module. An alphabetic list of variables precedes the formal description. The nomenclature in the TISED module is not completely identical to the current nomenclature of MEDEE-EUR, because a part of the variable names already existed before the new MEDEE nomenclature became entirely available.

4.2.1 Variable List

Exogenous variables

FEIO[vi,x]	- final energy demand of the manufacturing industry in a base year (1983) per energy carrier (vi) per sector (x)
FEIOVO[vi,x]	- final energy demand for non-production applications
GRUEI[vi,x,t]	- growth rate of specific energy consumption per energy carrier per sector per period
GRVAI[x,t]	- growth rate of value added per sector per period
ICF[x,t]	- industrial cogeneration capacity per sector per period
ND[i,t]	- number of working days per week per shift work class (i) per period
NH[i,t]	- number opening hours per day per shift work class per period
NW[i,t]	- number of working weeks per year per shift work class per period
QC	- balancing factor for overhead energy consumption (constant part)
QT[i,t]	- balancing factor for overhead energy consumption (variable part)
SNP[x,t]	- shares of production unrelated labor per sector per period
SSI[i,x,t]	- shares of the sectoral labor force per shift work class (index)
T	- number of hours per year (8760)

UCF - correction factor for (%) utilization of the
cogeneration capacity

Endogenous variables

CSSI[i.x,t] - shares of shift work corrected for lower energy
content of one shift labor (index)

FEIC[vi,x,t] - constant part of non-production- related energy
demand per energy carrier per sector

FEIP[vi,x,t] - energy demand related to production activities
per sector

FEIPO[vi,x] - idem for base year

FEIT[vi,x,t] - production time dependent part of non-
production-related energy demand per energy
carrier per sector

AFEI[vi/x,t] - final energy demand and its partitions

AFEIP[vi/x,t], etc. - aggregated by sector or by energy carrier

QSSI[i,x,t] - shares of shift work defined in terms of
corrected capacity

RSSI[x,t] - aggregation of CSSI, but restricted to 3- and 4-
shift activities

TSS[i,t] - share of production time (hours per year) in
total hours per year (T)

UTELxx[x,t] - gross momentary energy demand per energy carrier
per sector for four typical moments of the day

UTICxx[i.x,t] - utilized cogeneration capacity per shift work
class per sector for four typical moments of the day

NUTELxx[x,t] - net load of public network per shift work class
per sector for four typical moments of the day

Indices

i - indicator for shift work classes
i = 1: one shift
i = 2: two shifts
i = 3: three shifts
i = 4: four shifts

t - sightyear

t0 = 1983
t1 - t4 between 1984 and 2010

vi - energy carrier
vi = 1: natural gas
vi = 2: electricity

x - sectors of manufacturing industry
x = 1: food
x = 2: textile
x = 3: paper
x = 4: fertilizer
x = 5: basic chemicals
x = 6: remaining chemicals
x = 7: construction materials
x = 8: basic metal
x = 9: metal processing
x = 10: remaining industry

4.2.2 The Formal Structure

Prior to the distinction between production dependent and production independent energy demand the model starts with the assessment of the capital stock which is in use during typical periods of the day. This is carried out by transforming the shares of shift work per sectoral labor force (the sequence numbers of the equations correspond with the numbers in Figure C1):

$$QSSI[i,x,t] = \frac{SSI[i,x,t]/i}{\sum_i (SSI[i,x,t]/i)} \quad (1)$$

QSSI can be used for the production-unrelated energy demand, for the production-related energy demand we need a variable which is corrected for the overrepresentation of non-production labor in the one shift class:

$$CSSI[i,x,t] = SSI[i,x,t] - SNP[x,t] \quad \text{if } i = 1 \quad (2)$$

elsewhere $CSSI[i,x,t] = SSI[i,x,t]$.

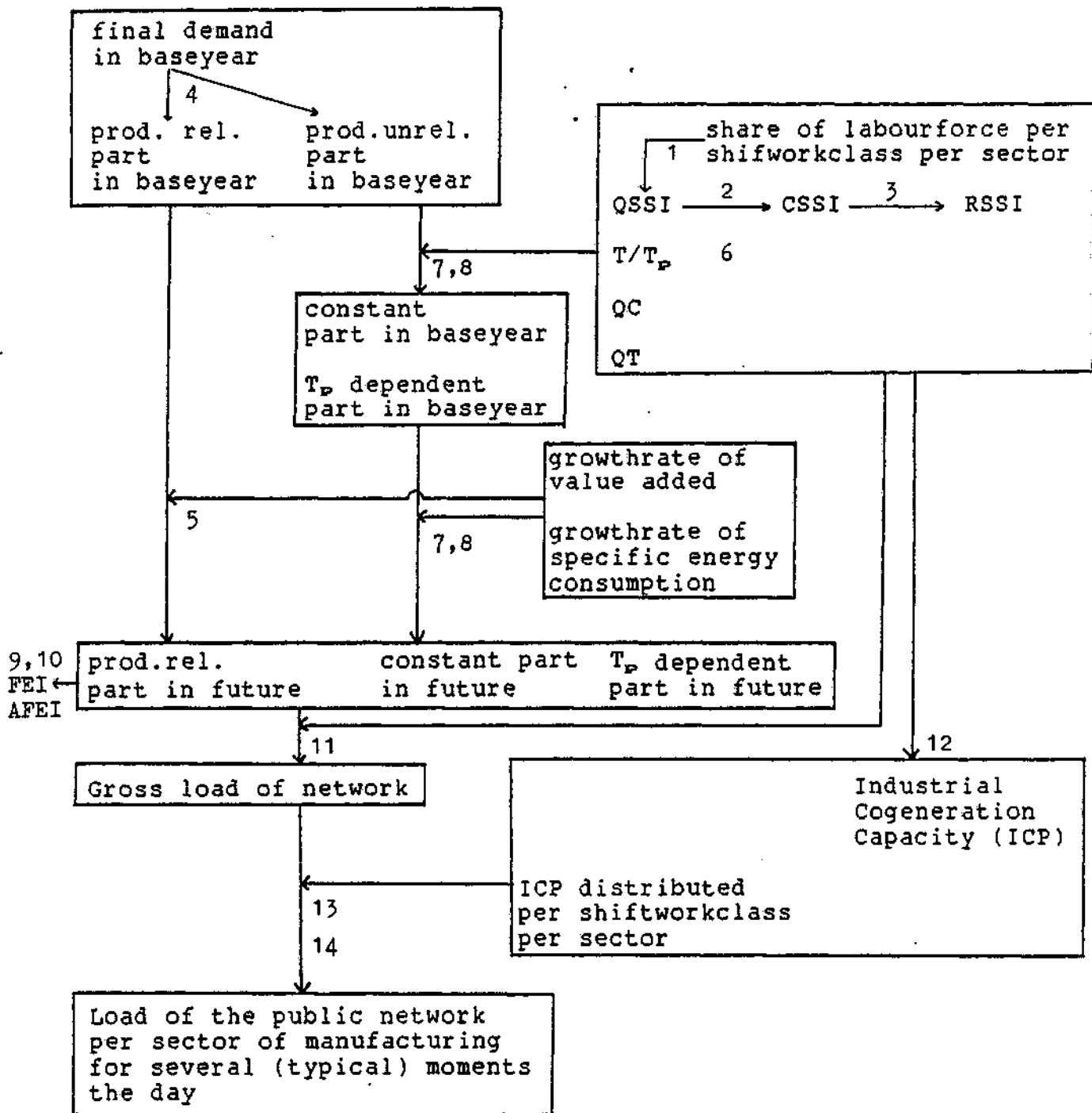


Figure C1. Global Structure of the TISED model.

However for some extremely energy-intensive sectors the shares of labor input are not proportional to the energy input. In these cases the shares have to be "biased" towards the 4-shift class, in those cases ($x = 4, 5, 8$; fertilizer, basic chemicals and basic steel respectively) CSSI is defined as follows:

$$\begin{aligned} \text{CSSI}[1,x,t] &= 0 & \text{CSSI}[2,x,t] &= \text{CSSI}[3,x,t] = 5, & (2a) \\ \text{CSSI}[4,x,t] &= 90 \end{aligned}$$

For the utilization of cogeneration power we assumed only the 3- and 4-shift work classes to be relevant. This assumption is in line with the common rule that cogeneration is not profitable in case of annual production times below 6000h..

$$\begin{aligned} \text{RSSI}[i,x,t] &= 0 \quad \text{if } i = 1, 2 & (3) \\ \text{elsewhere } \text{RSSI}[i,x,t] &= \sum_1 \text{CSSI}[i.x.t]. \end{aligned}$$

QSSI, CSSI and RSSI are the relevant capacity proxies. Subsequently the model deals with energy demand itself. It starts with calculating the production-related energy consumption in the base year (1983). Data on total final energy demand per industrial sector (FEIO) are available from the CBS energy statistics. Data on overhead energy demand (FEIOVO) are scarce (notably in the case of electricity use) and have a limited reliability.

$$\text{FEIPO}[vi,x] = \text{FEIO}[vi,x] - \text{FEIOVO}[vi,x] \quad (4)$$

The next step is de calculation of production-related energy demand in future years (FEIP). As the TISED model concentrates at the assessment of impacts on (future) network utilization the growth of annual energy demand is represented in a relatively simple manner. As is usual in the MEDEE concept the growth rates have to be obtained from other in depth studies (in this case the CPB-NELT study). Here future production-

related energy demand depends on the growth rate of output ¹ (GRVAI) and development of specific energy consumption (GRUEI).

$$FEIP[vi,x,t] = FEIPO[vi,x] \cdot (1 + GRVAI[vi,x,t] + GRUEI[vi,x,t])^{t-t_0} \quad (5)$$

In order to be able to calculate the production-unrelated parts of energy demand the model should determine first the share of production time per shift work class per period in the total number of hours per year (T):

$$TSS[i,t] = \frac{(NH[i,t] \cdot ND[i,t] \cdot NW[i,t])}{T} \quad (6)$$

The constant part of the production-unrelated energy demand (FEIC) is defined as follows:

$$FEIC[vi,x,t] = \sum_i (QSSI[vi,x,t] \cdot (1-TSS[i,t]) \cdot QC \cdot (1 + GRVAI[vi,x,t] + GRUEI[vi,x,t])^{t-t_0} \cdot FEIQVO[vi,x]) \quad (7)$$

The formula states that FEIC is the sum (over the shift work classes) of the product of the capacity shares per shift work class with the share of non-production time in total time, the share of overhead utilization in non-production hours compared to production hours (here 0.5 is used) and (future) overhead energy consumption.

The production time dependent part (FEIT) can be defined in a similar way:

¹ The growth rate of output equals the growth rate of value added in most industries, except for the energy intensive sectors. The growth rates of these latter sectors (basic steel, basic chemicals, fertilizer) depicts the growth of physical output.

$$\begin{aligned} \text{FEIT}[vi,x,t] = \sum_i (QSSI[vi,x,t] \cdot TSS[i,t] \cdot QT[i,t] \cdot \\ (1 + \text{GRVAI}[vi,x,t] + \text{GRUEI}[vi,x,t])^{t-t_0} \cdot \\ \text{FEIQVO}[vi,x,t]). \end{aligned} \quad (8)$$

Notice that QT has no uniform value for the different shift work classes. QT and QC are determined in such a way that FEIT and FEIC add up to FEIQVO in the base year 1983. The complete final energy demand for future years is simply the sum of its constituent parts:

$$\text{FEI}[vi,x,t] = \text{FEIP}[vi,x,t] + \text{FEIC}[vi,x,t] + \text{FEIT}[vi,x,t] \quad (9)$$

In addition the model also aggregates the various elements of annual energy demand by sector (x), by energy carrier (vi) or both:

$$\begin{aligned} \text{AFEIP}[x,t] &= \sum_{vi} \text{FEIP}[vi,x,t] & (10) \\ \text{AFEIP}[vi,t] &= \sum_x \text{FEIP}[vi,x,t] \\ \text{AFEIT}[x,t] &= \sum_{vi} \text{FEIT}[vi,x,t] \\ \text{AFEIT}[vi,t] &= \sum_x \text{FEIT}[vi,x,t] \\ \text{AFEIC}[x,t] &= \sum_{vi} \text{FEIC}[vi,x,t] \\ \text{AFEIC}[vi,t] &= \sum_x \text{FEIC}[vi,x,t] \\ \text{AFEI}[x,t] &= \sum_{vi} \text{FEI}[vi,x,t] \\ \text{AFEI}[vi,t] &= \sum_x \text{FEI}[vi,x,t] \end{aligned}$$

Of course the variables defined above can be aggregated once again. This second aggregation yields the total annual final energy demand (AAFEI[t]) and its constituent parts (AAFEIP[t]), AAFEIC[t], AAFEIT[t]) of the manufacturing industry. In the TISED model this second aggregation is also carried out, but its exposition is however omitted here.

In the next stage the gross momentary final energy demand is defined. The gross and net momentary energy demand are calculated for four typical moments of the day. These moments correspond with switch times of the number shift work classes that is in operation. By taking a monday all four switch times can be used. The four typical moments are:

monday morning early 2h. (SN) - in weekends only 4-shift work capacity will be in operation
monday morning about 9.30h. (M1) - all shift work classes are in operation at that time
monday evening about 19h. (M2) - the one shift capacity is assumed to be out of operation
tuesday morning early 2h. (MN) - the one shift and two shift capacity is assumed to be out of operation.

The respective amounts of gross momentary energy consumption are calculated as follows:

$$UTEL_{xx}[vi,x,t] = \sum_i \left[\left[\frac{CSSI[i,x,t]}{(100-SNP[x,t])} \cdot \frac{FEIP[vi,x,t]}{(TSS[i,t] \cdot T)} \right] + \left\{ (QSSI[i,x,t]) \cdot \left[\frac{FEIT[vi,x,t]}{(TSS[i,t] \cdot T)} \right] + \left[\frac{FEIC[vi,x,t]}{T} \right] \right\} \cdot 277.8 \right]$$

if xx = SN --> i = 4
if xx = M1 --> i = 1, 2, 3, 4
if xx = M2 --> i = 2, 3, 4
if xx = MN --> i = 3, 4

In a sidestep the model assigns cogeneration capacity per sector to the production capacity operated by 3 or 4 shifts.

$$UTIC_{xx}[x,t] = \sum_i \left[\frac{CSSI[i,x,t]}{RSSI[x,t]} \cdot UCF \cdot ICP[x,t] \right] \quad (12)$$

if xx = 1 --> i = 3, 4
if xx = 2 --> i = 4

Next the load of the public network (= net momentary electricity demand) per sector can be calculated.

$$\text{NUTELSN}[vi,x,t] = \text{UTELSN}[vi,x,t] - \text{UTIC2}[x,t] \quad (13a)$$

$$\text{NUTELM1}[vi,x,t] = \text{UTELM1}[vi,x,t] - \text{UTIC1}[x,t] \quad (13b)$$

$$\text{NUTELM2}[vi,x,t] = \text{UTELM2}[vi,x,t] - \text{UTIC1}[x,t] \quad (13c)$$

$$\text{NUTELMN}[vi,x,t] = \text{UTELMN}[vi,x,t] - \text{UTIC1}[x,t] \quad (13d)$$

We are also interested in the aggregate network load of the manufacturing industry. This is like the foregoing aggregations:

$$\text{ANUTELxx}[vi,t] = \sum_x \text{NUTELxx}[vi,x,t] \quad (14)$$

It will be clear that it makes no sense to aggregate by energy carrier because each energy carrier will be provided through its own network.

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